Comparison of abdominal aortic aneurysm diameter measurements obtained with ultrasound and computed tomography: Is there a difference?

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Objectives: **Accurate diameter measurements of abdominal aortic aneurysm (AAA) with both computed tomography (CT) and ultrasound (US) are essential for screening, planning surgical intervention, and follow-up after endovascular repair. Often there is a discrepancy between measurements obtained with CT and US, and neither limit of agreement (LOA) nor correlation between the two imaging methods has been clearly established. The purpose of this study was to assess the paired differences in AAA diameter measurements obtained with CT and US in a large national endograft trial.**

Methods: **CT and US measurements were obtained from an independent core laboratory established to assess imaging data in a national endograft trial (Ancure; Guidant, Menlo Park, Calif). The study included only baseline examinations in which both CT and US measurements were available. Axial CT images and transverse US images were assessed for maximal AAA diameter and recorded as CT^{max} and US^{max}, respectively. Correlations and LOA were performed between all image diameters, and differences in their means were assessed with paired *t* test.**

Results: **A total of 334 concurrent measurements were available at baseline after endovascular repair. CT^{max} was greater than US^{max} in 95% (n = 312), and mean CT^{max} (5.69 ± 0.89 cm) was significantly larger ($P < .001$) than mean US^{max} (4.74 ± 0.91 cm). The correlation coefficient between CT^{max} and US^{max} was 0.705, but the difference between the two was less than 1.0 cm in only 51%. There was less discrepancy between CT^{max} and US^{max} for small AAA (0.7 cm, 15.3%) compared with medium (0.9 cm, 17.9%) and large (1.46 cm, 20.3%) AAA; however, the difference was not statistically significant. LOA between CT^{max} and US^{max} (−0.45-2.36 cm) exceeded the limits of clinical acceptability (−0.5-0.5 cm). Poor LOA was also found in each subgroup based on AAA size.**

Conclusions: **Maximal AAA diameter measured with CT is significantly and consistently larger than maximal AAA diameter measured with US. The clinical significance of this difference and its cause remains a subject for further investigation. (J Vasc Surg 2003;38:466-72.)**

The natural history of abdominal aortic aneurysm (AAA) has been defined primarily with ultrasound (US) and axial computed tomography (CT) measurements of aneurysm size.[1-5] Maximal aneurysm diameter is the strongest predictor of AAA rupture.[1,6-8] The published yearly expansion and rupture rates of AAA correlate significantly with maximal diameter, and the surgical literature has frequently used measurements derived from US and CT interchangeably.[6,8-14] Despite the assumed equivalency of diameter measurements obtained with US and axial CT, the exact relationship between the two methods of measurement has not been clearly defined.[15]

Current recommendations for management of AAA depend on precise determination of aneurysm size. Excluding symptomatic, ruptured, or false aneurysms, accepted operative indications for AAA repair include diameter larger than 5.0 to 5.5 cm and expansion of more than 0.5 cm over 6 to 12 months.[7-9,13,14] These recommendations are based on series that included both US or CT, or a combination of the two, for AAA measurement.[1,5,6,13,14,16] In addition, both US and CT are now used as the primary methods of surveillance after endovascular aortic repair. Endoleak may be detected with either study; however, the diameter of the residual AAA sac at US or CT is arguably the most important measurement and ultimately determines operative success in this setting.[15,17-21]

Several authors have noted a difference between AAA diameter measurements obtained with US and CT, with US usually resulting in a smaller AAA diameter than CT.[11,15-17] Although CT is considered the gold standard, evidence to support this is lacking. Despite the often noted discrepancies, these issues have not been adequately addressed in the literature, and in only a few studies has a direct comparison of AAA size at US and CT been performed.[11,15-17,22,23,24] As a result, an accepted correlation between the two methods has not been established. Of equal importance, the expected agreement between US-derived and CT-derived measurement of AAA diameter is largely unknown. The purpose of this study was to directly assess the difference in maximal AAA diameter measurements obtained with US and CT in a large national endograft trial. Correlation between the two imaging meth-

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ods is established and the limits of agreement (LOA) are defined.

METHODS

US and CT measurements were obtained from a core laboratory established as part of a national endograft trial (Ancure; Guidant, Menlo Park, Calif). As included in the Phase I and Phase II protocol approved by the US Food and Drug Administration, all patients underwent postoperative duplex US scanning and CT within 1 month after endograft placement. The current study included only baseline examinations in which both US and CT measurements of aneurysm diameter were available. Transverse US and axial CT images were independently assessed by two observers for maximal AAA diameter and were recorded as US^{max} and CT^{max}, respectively. The diameter of the AAA within the same axial CT section and perpendicular to CT^{max} was recorded as CT^{min}.

CT and US were performed at 29 separate centers (local sites), with numerous types of equipment, according to a protocol provided by the core laboratory. Each center met the approval requirements of the core laboratory; however, to serve as a local site the trial did not require accreditation of the center by the Intersocietal Commission for the Accreditation of Vascular Laboratories. The local sites were responsible for calibration of US equipment and placement of accurate measurement scales on the grayscale images. CT scans were obtained with 120 to 150 mL of nonionic contrast medium and included 3 mm sections in all cases. Initially, spiral CT was used; however, helical CT was used when it became available during the course of the study.

The hard copy US and CT images were sent to the core laboratory from the local sites. All of the local sites performed maximal diameter measurements, but these were not sent to the core laboratory and were not included in this study. Studies of poor quality, as determined by the core laboratory, were not assessed for maximal diameter and were excluded. No standardized assessment was used to correlate or compare measurements between centers. All measurements included in the study are those of the observers in the core laboratory; the authors did not remeasure US or CT scans. All measurements were made in blinded fashion. Each observer was blinded to the other observer's measurements, and the observers were blinded to CT results when assessing US scans, and vice versa. Calipers were used in all cases, and magnification was used at the discretion of the observer. Multiple measurements were often performed to arrive at the maximal diameter; however, the protocol did not require a preset number of measurements for either US or CT. This reflects real-world data collected in the course of clinical practice.

Aneurysms were classified as small (<5.0 cm), medium (5.0-6.5 cm), or large (>6.5 cm), according to the recommendations of the Society for Vascular Surgery/International Society for Cardiovascular Surgery reporting subcommittee,[24] and were further analyzed by group. Correlations were performed between all image diameters

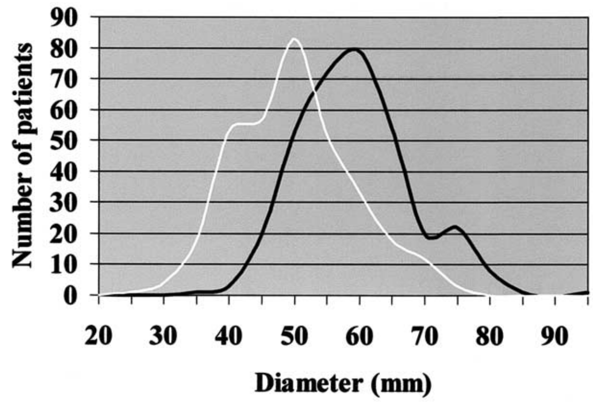

Fig 1. Measurement of maximal aneurysm diameter with CT^{max} *(black line)* (56.9 mm) compared with US^{max} *(white line)* (47.4 mm). CT^{max} significantly greater than US^{max} ($P < .001$).

with Pearson correlation analysis, and differences in their means were assessed with paired *t* test. LOA between CT and US was calculated with the method described by Bland and Altman.[25] In brief, LOA is comprised of two values, usually a positive (LOA-P) and negative number (LOA-N), that define a range in which 95% of the differences between two methods of measurements are expected to fall. In the current study, LOA-P was calculated by adding the standard deviation (SD) of the difference between CT^{max} and US^{max} (multiplied by 2) to the mean difference of CT^{max} and US^{max}. LOA-N was calculated by subtracting the SD of the difference between CT^{max} and US^{max} from the mean difference of the two. The clinically acceptable LOA was defined as LOA between −0.5 and 0.5 cm, which are the values (limits of agreement) between which 95% of the measured differences of US and CT are expected to fall. The LOA between US^{max} and CT^{min} was also calculated.

RESULTS

A review of the database identified 368 potential candidates for the study, with complete data with concurrent baseline US and CT measurements in 334 patients. Mean CT^{max} (5.69 ± 0.89 cm) was significantly larger ($P < .001$) than mean US (4.74 ± 0.91 cm) (Fig 1). The average difference between CT^{max} and US^{max} was 0.94 ± 0.69 cm. Seventy-five small aneurysms, 207 medium-sized aneurysms, and 52 large aneurysms were included in the study.

CT measurements were consistently larger than US measurements. Overall, CT^{max} was greater than US^{max} in 95% (n = 312). The difference in the two measurements was less than 1.0 cm in only 51% (n = 173), between 1.0 and 2.0 cm in 42% (n = 139), and greater than 2.0 cm in 6% (n = 22). Mean CT^{max} (5.47 cm) in the group with less than 1.0 cm difference was significantly smaller that CT^{max} in the other two groups, 5.81 cm and 6.67 cm, respectively ($P < .05$). Although the difference between CT^{max} and US^{max} was statistically significant, the correlation (Fig 2) between CT^{max} and US^{max} in all groups was good (correlation coefficient, 0.705).

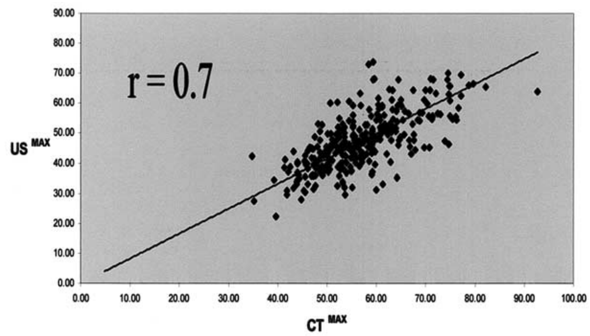

Fig 2. Correlation between CT^{max} and US^{max}.

Mean difference in CT^{max} and US^{max} in small AAA was 0.71 cm, with a mean percentage difference of 15.3%. By comparison, there was a greater discrepancy between CT^{max} and US^{max} in medium (0.91 cm, 17.4%) and large (1.46 cm, 20.3%) aneurysms. Although there was a trend toward an increasing difference of CT^{max} and US^{max} with increasing AAA size, statistical significance was not achieved secondary to the relative limited number of patients with small and large AAA.

LOA was calculated from the mean difference of US^{max} and CT^{max} (0.94 cm) and the SD of the difference (0.69 cm). LOA between CT^{max} and US^{max} was poor, −0.45 to 2.36 cm (Fig 3). This implies that in 95% of cases the difference in CT^{max} and US^{max} is expected to be between these values, which clearly exceeds the limit of clinical acceptability. Subgroup analysis demonstrates that LOA between CT^{max} and US^{max} was poor, regardless of AAA size: small, −0.30 to 1.7 cm; medium, −0.50 to 2.31 cm; or large, 0.14 to 2.74 cm.

Evaluation of CT^{min} was also performed. Mean CT^{min} (5.12 ± 0.83 cm) was by definition smaller than CT^{max}, with average difference between the two of 0.59 ± 0.43 cm. However, CT^{min} was on average larger than US^{max} by 0.39 ± 0.61 cm. Comparison of the means demonstrates less of a difference between CT^{min} and US^{max} (0.39 cm) than between CT^{max} and US^{max} (0.94 cm) ($P < .001$). LOA was also better between CT^{min} and US^{max} compared with CT^{max} and US^{max}: −0.92 to 1.60 cm versus −0.45 to 2.36 cm (Fig 4). Furthermore, there was better correlation between CT^{min} and US^{max} (0.77) than between CT^{max} and US^{max} (0.70). The best correlation (0.87) was found between CT^{min} and CT^{max}.

DISCUSSION

On the basis of determination of AAA diameter with physical examination and plain radiography, the yearly expansion rate of AAA has been calculated and maximal AAA diameter established as the best predictor of aneurysm rupture.[1,4,6-10] These findings have been validated by subsequent investigations in which US and CT measurements of aneurysm diameter were used to define the natural history of AAA.[2,3,5,6,10] CT is currently accepted as the gold standard for assessment of AAA size, but there is no conclusive evidence that it is more accurate than US.[11,16,19] Despite numerous reports that document variation between US and CT determination of AAA size, both methods are considered reliable and have been used interchangeably to establish thresholds and indications for surgical intervention.[6,8,10-14] Specifically, in the UK Small Aneurysm Trial,[26] maximal AAA diameter at US was the determining factor in patient selection and in relegating patients to continued observation or surgery, whereas in other trials and proposed classification systems, eg, the Aneurysm Detection and Management Trial (ADAM),[27] maximal diameter at both US and CT has been used.[13,14] The discrepancy between US and CT determination of aneurysm size questions the validity of natural history data and recommendations derived from studies that used US and CT measurements interchangeably. Inconsistency between the two methods can lead to errors in surgical decision-making that may be magnified in this era of endovascular AAA repair, in which precise measurements are mandatory for successful preoperative and postoperative management.

The current study compared maximal AAA diameter measurements obtained with US and CT in a national endograft (Ancure) trial. As demonstrated in earlier reports,[11,15,16] maximal AAA diameter at CT (CT^{max}) was consistently larger than maximal diameter at US (US^{max}). CT^{max} was larger than US^{max} in more than 95% of the cases in this study, with a mean difference between the two of 0.94 ± 0.69 cm. That CT measurements of AAA were larger than US is not surprising; however, that mean difference between the two was almost 1 cm was somewhat unexpected and greater than the difference observed by others in similar investigations.[11,15-17]

Several explanations for the discrepancy between US and CT measurements have been described. First, CT measurements, unlike US measurements, most commonly include the full thickness of the AAA wall.[15,17,23] Lack of high-resolution grayscale imaging may have hindered US measurements in the past; however, improved grayscale resolution with modern US equipment should minimize this difference. Second, CT^{max} in many of these studies is defined as the maximal cross-sectional AAA diameter in any direction, while US^{max} is defined as the largest anteroposterior or transverse diameter.[16,27] In this case, US and CT may not measure maximal diameter in the same axis, and in an asymmetric AAA the mean CT measurements would logically be greater than the US measurements. Finally, axial sections at CT may represent an oblique cut of an AAA if the aneurysm is angulated, leading to overestimation of size. As suggested by Lederle et al,[16] US measurements are less affected by tortuosity, because the US probe can be positioned to obtain a true cross-section or orthogonal view of the AAA and, in this situation, yields a more accurate measurement of diameter. In our opinion, all of these factors may have contributed to larger CT measurements of AAA diameter in the current study, and they emphasize that neither US nor CT should be accepted as

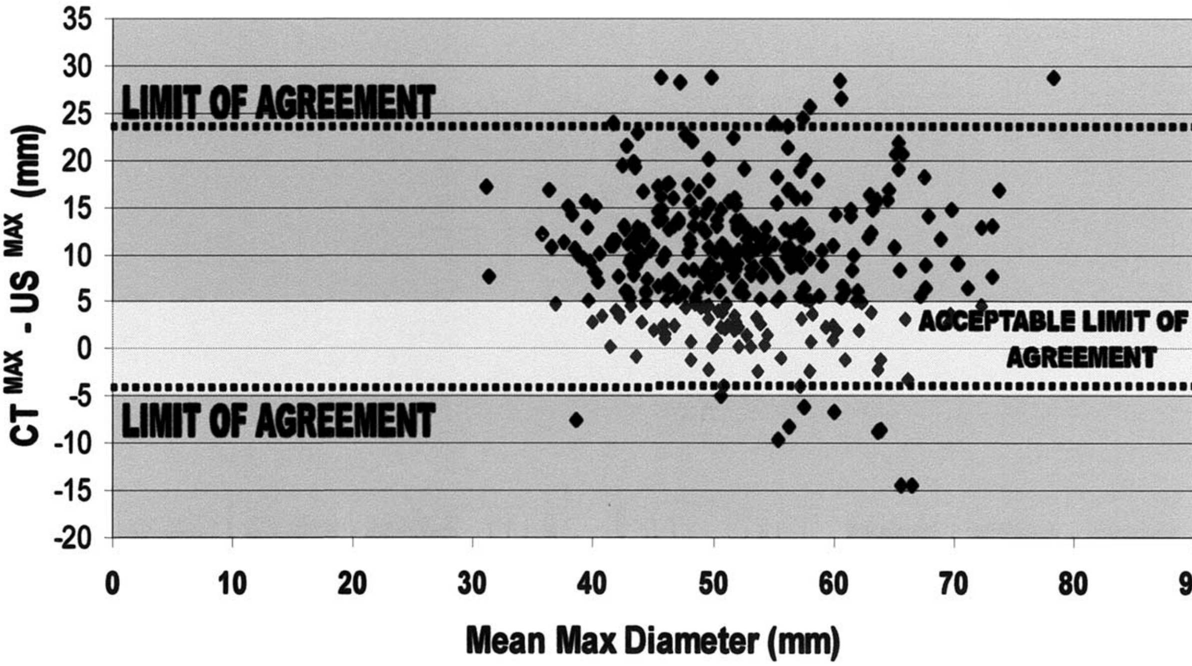

Fig 3. Limits of agreement *(broken lines)* between CT^{max} and US^{max} (−4.5-23.6 mm) compared with clinically acceptable limits of agreement *(highlighted area)* between CT^{max} and US^{max} (−5.0-5.0 mm).

the gold standard for determination of maximal AAA diameter.

Although the difference between CT^{max} and US^{max} in the current study was larger than reported in most series, it was comparable to the difference recently noted by Pages et al.[17] after endovascular aortic repair. The ADAM investigators[16] also assessed AAA size with US and CT, and demonstrated significant variability. Much like in our study, in which the patients were part of a larger trial, the primary focus of the ADAM study was not to compare the difference between US and CT, and therefore a strict protocol for measuring and reporting maximal AAA diameter was not followed. The authors suggested that lack of agreement between US^{max} and CT^{max} in the ADAM trial, and perhaps in the current study, may more accurately reflect what can be expected in the usual clinical setting. Many of the studies that demonstrated a closer relation between US and CT measurements were performed in accordance with a strict protocol provided in a research setting.[12,15,19,23] Adherence to such protocols can minimize the discrepancy between US and CT measurements, but it may not be feasible or practical to follow them in everyday practice. Lack of consistency between individual noninvasive laboratories, vascular surgeons, and radiologists in measuring AAA diameter may account for both intraobserver and interobserver variability often encountered, and highlights that standardization of assessment and reporting of AAA measurements obtained with US and CT is needed.

If the difference between US and CT demonstrated in our study is a true representation of clinical practice, several concerns regarding current management of AAA must be addressed. In a conglomeration of studies,[9-14,26,27] US and CT measurements were used interchangeably to define the natural history of AAA. In addition, the method by which maximal AAA diameter was measured with US and CT is not well-defined and is often inconsistent between these studies.[8,15-17,28] For example, US was used to screen and follow up patients in the UK Small Aneurysm Trial, which formed the basis for many of the recommendations now used in clinical practice.[26] Currently, however, most of the clinical decisions with regard to AAA management and surgical intervention are based on CT, not US. Is it possible that the 5.0 to 5.5 cm AAA measured with US in the UK Small Aneurysm Trial would have been more than 6.0 cm if measured with CT? If so, the validity of the data and their ability to lead to effective management must be questioned.

Despite lack of agreement of AAA diameters in our comparison, correlation between US^{max} and CT^{max} was good. Correlation of 0.70 is slightly less than that reported by others,[12,15,19] and indicates that, although there was a significant difference between the two, the degree of difference was relatively consistent. However, calculating LOA between US^{max} and CT^{max} highlights that the correlation coefficient between two methods of measurements may be misleading. It is expected that there will be good correlation between CT and US, because they both measure the same variable.[25] Correlation, however, does not consider the absolute difference between two measurements. LOA calculation (−0.45-2.36 cm in the current study) demonstrates that the difference between CT and US based on this

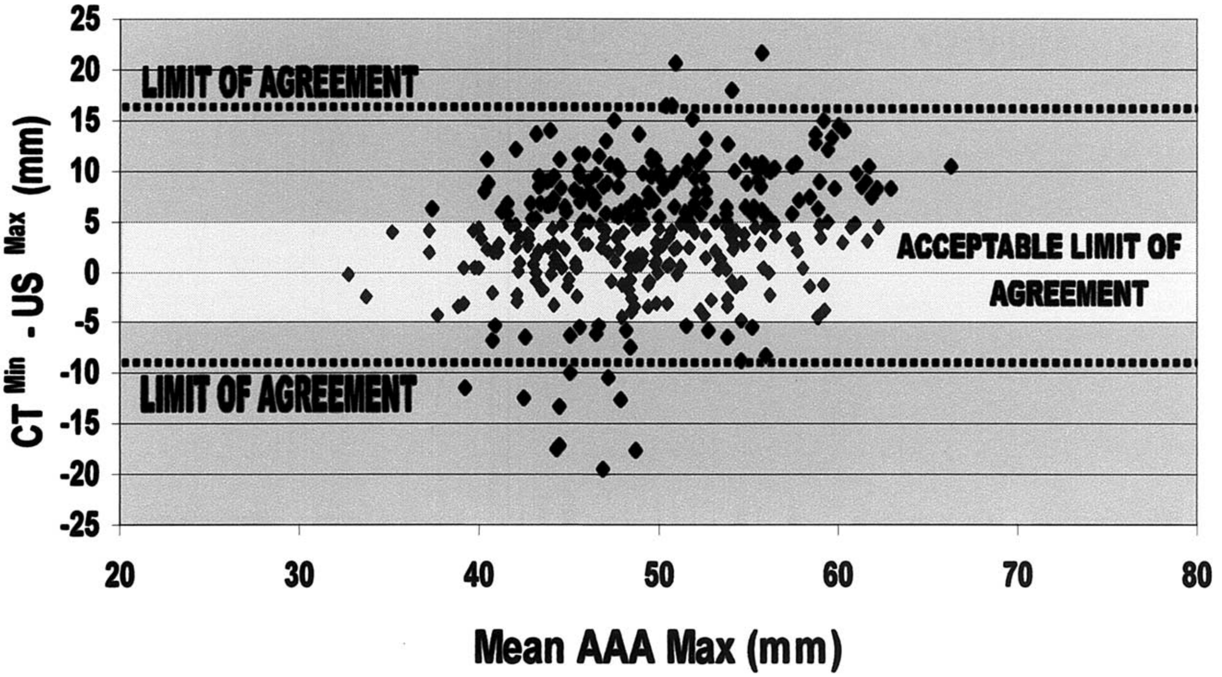

Fig 4. Limits of agreement *(broken lines)* between CT^{min} and US^{max} (−9.2-16.2 mm) compared with clinically acceptable limits of agreement *(highlighted area)* between CT^{min} and US^{max} (−5.0-5.0 mm).

series is clinically unacceptable. For CT and US measurements to be used interchangeably with confidence, LOA would need to be no more than plus or minus 0.5 cm. This would ensure that 95% of the time there would be less than a 5% chance that the difference between US^{max} and CT^{max} exceeds 0.5 cm.

It has been proposed that in cases of significant aortic angulation CT^{min} represents the "true" maximal AAA diameter better than CT^{max} does.[5,11,16] A large difference between CT^{max} and CT^{min} suggests that the CT scan represents an oblique section through the aneurysm, leading to overestimation of maximal size with CT^{max}. As expected, we found that the mean difference between US^{max} and CT^{min} (0.39 ± 0.61) was less than the mean difference of US^{max} and CT^{max} (0.94 ± 0.69). In addition, there was better correlation (0.77) and LOA between US^{max} and CT^{min}. The current study does not provide an explanation for this finding, but it suggests that US, like CT^{min}, may be more accurate in determining maximal diameter in cases of aortic angulation. Unlike axial CT sections, US has the ability to correct for angulation. Although we did not directly assess angulation in this study, it can be assumed that in a large series of patients with AAA many of the aneurysms will demonstrate a significant degree of angulation. The difference of almost 1 cm between US^{max} and CT^{max} may have been somewhat falsely elevated because of a subgroup of patients with severely angulated AAA. In summary, the unexpectedly large difference between CT^{max} and US^{max} in this study may be explained by overestimation of maximal size at CT, especially in AAA with significant angulation.

CONCLUSIONS

Assessment of AAA diameter with CT and US is not equivalent. Maximal AAA diameter at CT is significantly and consistently larger than maximal diameter at US, and LOA is unacceptable. The explanation for the difference between the two methods is likely multifactorial. To ensure effective management of AAA, standardization for reporting of maximal AAA diameter obtained at CT and US should be adopted in both the research and clinical settings. Neither CT nor US should be considered the gold standard for measuring maximal AAA size. Further investigation is needed to clarify the observed difference between CT and US measurements and to define the accuracy of each method independently.

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DISCUSSION

Dr H. Edward Garrett, Jr (Memphis, Tenn). The authors have reviewed the abdominal ultrasound and CT measurements taken 1 month after endovascular repair of abdominal aortic aneurysm using the Ancure graft in 334 patients enrolled in the FDA trial whose studies were submitted to the core lab. The data reveal significant discrepancies in the maximal size of the aneurysm as measured by ultrasound and CT. Although the CT measurements tended to be larger than the ultrasound measurements, the difference between the measurements was inconsistent, and the limit of agreement was unacceptable. Limit of agreement is a statistical term most of us are not accustomed to using. It defines the range of difference expected between the maximum CT and ultrasound diameters. In this review, the range for all aneurysm sizes was too broad to be clinically useful.

What does this mean? It means that isolated measurements of abdominal aortic aneurysms taken by different technicians at different locations at unknown axis to the central blood flow will have significant discrepancies. These measurements were not taken to compare the accuracy of the instruments and cannot be used to establish that accuracy. Was the same protocol for measurement used in every case? Were measurements taken perpendicular to the central column of flow? Were the instruments standardized and calibrated? Were CT measurements taken manually or with computer software and from what size images?

We and others have shown that when a phantom is measured by CT, ultrasound, and digital caliper, remarkable agreement is obtained. Differences in measurement of a patient's abdominal aortic aneurysm must therefore be explained by variation in location, axis, and technique, as many authors have demonstrated. Several published series document that ultrasound consistently measures the diameter of an aneurysm somewhat smaller than a CT scan does, especially in the transverse diameter where wall thickness is more difficult to assess. These authors found that when the CT max and min were similar in diameter, indicating little tortuousity, the limit of agreement between CT and ultrasound was more acceptable. It can be assumed then that much of the discrepancy in this study is secondary to CT overestimation of tortuous aneurysms. Thomas from St. Richard's Hospital, UK, published a single-center study comparing CT and ultrasound measurements of aneurysms in 1993 and found a more acceptable limit of agreement between 1.9 and 10 mm at the 95% confidence limit. Filinger, Bebe, and others have demonstrated that the current gold standard for measurement of abdominal aortic aneurysm is a 3D reconstructed CT angiogram properly performed with adequate contrast and without patient motion. Measurements must be taken perpendicular to the central column of flow. To the degree that ultrasound and conventional CT scan can duplicate these criteria, agreement between the studies will occur. Three-dimensional ultrasound also shows promise of accurate and reproducible measurements of aneurysms. It should be noted, however, that as the post–endovascular repair aneurysm sac remodels, it occasionally changes from a circular to a more oval shape. Diameter measure-